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SCHEDULE 15-2
DESIGN AND CONSTRUCTION

PART 3
DESIGN AND CONSTRUCTION REQUIREMENTS - TUNNEL

ARTICLE 1 INTRODUCTION

(a) This article describes the Design and Construction requirements related to Tunnels.

(b) Tunnels comprise the following:

(i) Tunnels constructed using a TBM, hereinafter referred to as bored Tunnels;

(ii) Tunnels and Stations constructed using SEM that involve mechanized excavation or controlled blasting methods, hereinafter referred to as mined Tunnels, and Stations, as the case may be; and

(iii) Tunnels, Stations and shafts constructed by cut-and-cover methods, hereinafter referred to as cut-and-cover Tunnels, cut-and-cover Stations and shafts, as the case may be;

(iv) Temporary decking and support of excavations for cut-and-cover Tunnels, cut-and-cover Stations, shafts, and retaining walls;

(v) Cross passages between Tunnels, niches, sumps and other excavations within or adjacent to the Tunnels; and

(vi) Initial support and permanent support and lining for bored and mined Tunnels, and mined Stations.

(c) The scope comprises the downtown OLRT Tunnels and associated underground Structures, and the Tunnel and approaches between the Guideway and the MSF.

(d) Project Co shall determine the specific means and methods for Tunnel Construction consistent with the Design and Construction criteria specified herein, except as may be otherwise specified in the remaining articles in this Part 3.

1.1 Scope

(a) Part 3 describes the requirements for Design, Construction, the relevant standards, Design Criteria, and other technical requirements that apply to Tunnel elements.

(b) Specific Design and Construction requirements that shall be integrated with other contract requirements, shall include but are not limited to the following:

(i) Spaceproofing

A. Track Alignment - refer to Part 1 Article 1 – Physical Layout, Part 1 Article 2 – Operational Performance Requirements and Part 2 Article 2 – Alignment and Geometric Design Criteria.

B. Opening size relative to minimum clearance envelopes and required Infrastructure - refer to Part 1 – General Requirements, Part 2 – Design and Construction Requirements – Guideway and Part 5 – Design and Construction - Stations;

(ii) Permanent retained earth structures other than Tunnels – Refer to Part 1 Article 21 – Civil Structural Design Criteria;

(iii) Protection of Existing Adjacent Structures during Construction – refer to Part 1 Article 20 – Protection of Existing Adjacent Structures;

(iv) Corrosion control and stray current protection - refer to Part 1 Article 14 – Corrosion Control;

(v) Requirements associated with future developments – refer to Part 1 Article 19 – Future Adjacent Construction Requirements;

(vi) Geotechnical Requirements – refer to Part 1 Article 12 – Geotechnical/Foundation Design Criteria; and

(vii) Environmental requirements – refer to Schedule 17 – Environmental Obligations.

(c) Construction shall be sequenced to mitigate impacts to the surrounding Infrastructure, including vehicular and pedestrian circulation, access to and egress from adjacent structures, and disruption to existing Utilities. Such Construction sequencing shall consider the order of prosecution of the Work, including the need for multiple shifts, night-time or weekend Work and material deliveries and removal of excavated materials. Refer to Part 1 Article 22 – Implementation Constraints, and Part 7 – Traffic and Transit Management and Construction Access.

ARTICLE 2 GENERAL STRUCTURAL DESIGN CRITERIA

2.1 Scope

(a) This article specifies structural Design parameters and criteria that are common to structural linings for Tunnel structures. Design and performance criteria for temporary excavation support for cut-and-cover structures, initial ground support for bored and mined Structures and permanent Structures are discussed separately.

2.2 Performance Criteria

(a) Selection of Tunneling Method

(i) The selection of the tunneling methods to be employed shall be based on such factors as geology, the dimensions of the Tunnel, the stability of the opening during excavation and prior to placement of the initial support, minimization of ground movements and detrimental impacts of groundwater flow into excavations, and protection of Existing Adjacent Structures.

(ii) Tunneling methods shall be selected so that adequate regard is given to avoiding hazards and mitigating foreseeable risks to those carrying out the Works and others that may be affected.

(b) The temporary excavation support and initial support shall be designed and constructed to support all applicable ground, groundwater, Construction and temporary loads per applicable Design Criteria and standards during Tunnel excavation and until installation of the permanent lining. Maintain the integrity of Existing Adjacent Structures during Construction and limit their deformation within acceptable limits.

(c) Minimum Tunnel Design requirements shall consider:

(i) Durability of permanent lining to support applicable internal and external loads over the structure's Design Life;

(ii) Permanent support and preservation of Existing Adjacent Structures;

(iii) Collection, treatment and disposal of all drainage and intercepted water, where applicable;

(iv) Protection against degradation of permanent lining, for whatever reason, including the presence of gas and soil, rock, and groundwater contaminants; and

(v) Serviceability requirements during operations over the Tunnel Design Life.

2.3 Temporary Excavation Support and Initial Support

(a) Codes, Standards and Manuals

(i) The Design and Construction of the Works shall comply with the criteria contained in this Article, and all standards, regulations, policies, Applicable Law, guidelines or practices applicable to the Project, including but not limited to each of the following Reference Documents. In the event of a conflict between criteria, commitments or requirements contained within one document when compared with another, the more stringent shall apply:

A. Codes

i. CAN/CSA A23.3 - Design of Concrete Structures.

ii. CAN/CSA S16 - Design of Steel Structures.

iii. CAN/CSA S6 - Canadian Highway Bridge Design Code.

iv. CAN/CSA G30.18 - Carbon Steel Bars for Concrete Reinforcement.

v. ASTM A185 - Standard Specification for Steel Welded Wire Reinforcement, Plain, for Concrete.

vi. AREMA – Manual for Railway Engineering.

vii. CN Guidelines for Design of Railway Structures, Canadian National Railway, Edmonton, Alberta.

B. Design References

i. ASCE Technical Committee on Tunnel Lining Design, Guidelines for Tunnel Lining Design, edited by T. O'Rourke, 1984.

ii. John M. and Mattle B. (2003), Shotcrete Lining Design: Factors of Influence, RETC 2003 Proceedings, 726-734.

iii. Technical Report No. 63, Guidance for the Design of Steel-Fibre-Reinforced Concrete, The Concrete Society, CCIP-017, March 2007.

iv. Specification for Tunnelling, British Tunnelling Society and Institution of Civil Engineers.

v. Tunnel Lining Design Guide, British Tunnelling Society and Institution of Civil Engineers.

vi. Canadian Foundation Engineering Manual, Canadian Geotechnical Society.

(b) Materials

(i) Materials shall be selected by Project Co for strength, geometry, initial set, toughness, and other qualities required for the means and methods selected to perform the Work and in accordance with requirements, standards, and information specified herein.

(ii) Temporary ground anchoring systems used for temporary excavation support or initial support shall consider the location of Utilities and comply with right of way restrictions.

(c) Loads: The potential for unsymmetrical vertical loads or unbalanced horizontal loads due to variations in ground conditions or properties shall be accounted for as follows:

(i) Soil loading on temporary excavation support for cut-and-cover Structures and shafts: Lateral soil loading shall be based on the soil properties as determined by Project Co and type of support proposed;

(ii) Rock loading on temporary excavation support for cut-and-cover Structures and shafts: Lateral rock loading shall be determined through analysis of the rock mass as a continuum and failure of rock wedges;

(iii) Rock and ground loading on initial support for bored and mined Tunnels: Rock and ground loads on the initial support and the interaction between the support measures and the ground shall be evaluated with methods which consider the following modes of failure of the rock or ground mass and corresponding analysis procedures:

A. Failure of discrete rock blocks shall be analyzed using the wedge and discrete block analysis method;

B. The rock or ground mass shall be modeled as a continuum considering potential failure modes. Such analysis procedures shall consider effects of in-situ stresses and stress re-distribution, the strength of the rock mass including the effect of discontinuities on rock mass strength, and stress re-distribution ahead of the Tunnel face. This analysis shall be done using numerical analysis methods;

C. Potential failure of the Tunnel face shall be analyzed by three-dimensional discrete block/wedge stability analysis, and numerical analysis; and

D. Time dependent deformation (swelling) of the shale bedrock with numerical methods where applicable;

(iv) Structural Dead Loads

A. Structural dead loads of the initial support for mined Tunnels can be ignored since shotcrete, rock dowels, steel lattice girders, and other support elements form a composite structure with the surrounding rock mass.

B. Dead loads of structural and non-structural elements for all temporary structures shall be based on unit weights and computed volume of the materials;

(v) Live Loads

A. Live loads on the initial support of bored and mined Tunnels need not be considered except at low cover areas where access to the area above the bored or mined Tunnels by Construction Equipment traffic or other live loads is possible.

B. Design live load for temporary structures shall consist of any non-permanent load placed on or in the temporary structure.

C. Temporary Bridges to provide access for vehicles above the cut-and-cover sections of underground structures shall be designed for traffic loading.

D. Temporary surcharge loads due to Construction Equipment or traffic adjacent to cut-and-cover structures or shafts shall be considered;

(vi) Hydrostatic Pressure

A. Hydrostatic pressure shall be applied to temporary excavation support and initial support systems as appropriate if water-tight support systems are required based upon Project Cos approach to hydrogeology; and

(vii) Thermal Forces

A. Thermal loads shall be considered for temporary excavation support and initial support systems where applicable.

(d) Monitoring Requirements: Project Co shall integrate the following monitoring requirements with other monitoring requirements outlined in this Schedule 15-2:

(i) A systematic monitoring program shall be implemented to monitor the performance of all temporary excavation support and initial support installations;

(ii) The monitoring systems shall be capable of: detecting ground movement and settlement, movement of Existing Adjacent Structures and Utilities, and providing data necessary to assess the structural performance of initial support and temporary excavation support systems;

(iii) The logs and survey notes shall include the following information:

A. Measurements of in-tunnel or other deformations;

B. Construction loading or other activities in the vicinity of instrumentation; and

C. Any cracks in or damage to any in-tunnel, other structures, or other events;

(iv) Temporary excavation support and initial support shall be monitored using a management system based on Trigger Levels and Action Levels, as specified elsewhere; and

(v) To ensure that the excavation and support for Tunnels are proceeding as planned, review procedures shall be developed that will allow all relevant factors to be considered when evaluating the performance of the temporary excavation support and initial support. Project Co shall develop contingency plans to address temporary or initial support that fails to meet the performance requirements developed by Project Co.

2.4 Permanent Support and Lining

(a) General

(i) Mined structures shall utilize a double shell lining system consisting of both initial support and a permanent lining separated by a sheet waterproofing membrane system except as noted in this article. The permanent lining of mined structures shall be constructed of cast-in-place reinforced concrete or reinforced shotcrete after the initial support and waterproofing have been placed.

(ii) The permanent lining for cut-and-cover Tunnels and cut-and-cover Stations, and vertical circulation shafts at Stations shall be constructed of cast-in-place reinforced concrete.

(iii) For emergency ventilation shafts and emergency ventilation Tunnels, the permanent lining may be cast-in-place reinforced concrete or reinforced shotcrete.

(iv) Bored Tunnels shall utilize a permanent lining comprising either bolted-and-gasketed precast concrete segments, or a cast-in-place reinforced concrete lining with a sheet waterproofing membrane system.

(v) Permanent ground anchoring systems shall only be used for resisting uplift forces.

(b) Allowable Post-Construction Groundwater Seepage

(i) Permanent treatments shall be employed as required to ensure that any water present on internal surfaces does not affect the Safety, durability and function of the Tunnels.

(ii) Project Co shall ensure that any groundwater seepage into the completed Tunnels does not drip or flow onto or over Tracks, walkways, egress passages and plant and Equipment rooms.

(iii) To prevent groundwater seepage from entering onto specified Tunnel features, a collection system shall be implemented that collects any seepage from the Tunnel roof, invert and walls and directs it to the drainage system.

(iv) Notwithstanding groundwater seepage and waterproofing requirements, water ingress through permanent linings during the Maintenance Term shall not exceed the following inflow criteria:

A. 0.8 liters per square meter of Tunnel perimeter per day for segmental linings; and

B. 0.2 liters per square meter of Tunnel perimeter per day for other permanent linings.

(v) The specified degree of watertightness shall be achieved prior to Final Completion, and shall be maintained throughout the Maintenance Term.

(c) Codes, Standards and Manuals

(i) The Design and Construction of the Works shall comply with the criteria contained in this Article, and all standards, regulations, policies, Applicable Law, guidelines or practices applicable to the Project, including but not limited to each of the following Reference Documents. In the event of a conflict between criteria, commitments or requirements contained within one document when compared with another, the more stringent shall apply:

A. Codes

i. NBC

ii. OBC

iii. CAN/CSA A23.1 Concrete Materials and Methods of Concrete Construction

iv. CAN/CSA A23.2 Methods of Test and Standard Practices for Concrete

v. CAN/CSA A23.3 Design of Concrete Structures

vi. CAN/CSA S6 Canadian Highway Bridge Design Code

vii. CAN/CSA S6.1 Commentary on Canadian Highway Bridge Design Code

viii. CAN/CSA A16 Design of Steel Structures

ix. AREMA – Manual for Railway Engineering

x. ACI 365 -- Service-Life Prediction

B. Design References

i. ITA Fire Guidelines.

ii. Specification for Tunnelling, British Tunnelling Society and Institution of Civil Engineers.

iii. Tunnel Lining Design Guide, British Tunnelling Society and Institution of Civil Engineers

iv. Proctor, R.V. and White, T.L., *Rock Tunneling with Steel Supports*. Youngstown, Ohio: Commercial Shearing, Inc., 1988

v. Hashash, Y.M.A. et al., 2001, *Seismic Design and Analysis of Underground Structures*, Tunneling and Underground Space Technology 16, pp. 247-293,

(d) Federally Mandated Stations shall meet or exceed the requirements of both the OBC and the NBC. Non-Federally Mandated Station need only meet the requirements of the OBC.

(e) Materials

(i) Concrete

A. The minimum 28 day strength of structural concrete shall be 40MPa, except for working slabs, and mass or unreinforced concrete.

B. The concrete mix Design shall include measures to provide the durability and density required to attain the Design Life and for the prevention of the deleterious effects of erosion, groundwater attack, acid attack and sulfate attack as applicable.

C. Special measures shall be taken to minimize the possible deleterious effects of excessive heat of hydration in thick concrete sections.

(ii) Shotcrete

A. The minimum 28 day strength of shotcrete shall be 40 MPa.

B. The shotcrete mix Design shall include measures to provide the durability and density required to attain the Design Life.

(iii) Reinforcement

A. Reinforcement shall comply with CAN/CSA G30.18.

B. Welded wire fabric shall comply with ASTM A185.

C. Steel fibres may be used for reinforcing of bolted and gasketed segmental pre-cast concrete linings provided all Design requirements of this article are met.

D. Steel or macro synthetic fibres may be considered for reinforcing of the permanent linings of emergency ventilation structures only.

(iv) Structural Steel

A. Structural steel shall conform to CAN/CSA G40.21.

(f) Durability

(i) General

A. In the Design of Tunnels for durability, reliance must not be placed solely on the recommendation of Design codes and standards. In selecting materials and measures for durability, due account must be taken of the environment in which the Tunnels are situated and to the monitoring and maintenance Work required to achieve the Design Life. Project Co shall make its own assessment of the performance criteria for Tunnels in terms of:

i. the micro-environment;

ii. potential deterioration mechanisms in this micro-environment;

iii. the likely material life;

iv. the feasibility and cost of in-situ monitoring, maintenance and/or repair and replacement;

v. the necessity of providing additional protection (e.g. coatings); and

vi. the consequences of failure.

B. Results of testing of representative samples of soil and groundwater for various formations encountered on the Project are outlined in the Reference Documents. Project Co shall evaluate these results and assess the need for additional testing to comply with the following requirements in this article.

i. Project Co shall perform sufficient exploration and chemical testing for ground soil and water samples that are potentially harmful to permanent materials in the vicinity of underground Structures so that a rational assessment of the environment can be made and considered in the durability assessment. Types of cement and aggregate and the type and quality of concrete suitable for permanent Works below ground shall be designed to achieve the required Design Life. Project Co shall demonstrate how their Design achieves the Design Life through an analysis such as that set forth in ACI 365.

ii. Project Co shall perform sufficient exploration and chemical testing for groundwater samples that have the potential to cause blockage of drainage systems through the precipitation of insoluble salts in the vicinity of Tunnels. The drainage system suitable for Tunnels shall be designed to achieve the required Design Life.

(g) Waterproofing of Tunnels

(i) The full perimeter of Undrained Structures shall be protected with a sheet waterproofing membrane system except as indicated in this article.

(ii) The arch and sidewalls of Drained Structures shall be protected with a sheet waterproofing membrane system except as indicated in this article.

(iii) Waterproofing membrane systems provided for underground structures that incorporate a permanent cast in-situ concrete or shotcrete lining shall be:

A. Installed in accordance with the manufacturer’s specifications;

B. Classified as self-extinguishing;

C. Compatible with the type of waterstops used;

D. Certified by the manufacturer that no components of the waterproofing system shall leach out over the Design Life of the Project and deleteriously affect the durability of any of the following:

i. the waterproofing membrane;

ii. the geotextile drainage/protective layer; and

iii. other plastic materials or PVC materials such as waterstops; and

E. Protected from damage at all times. With the exception of blind forming techniques (i.e single sided forming) or where shotcrete is placed as the final lining, in conjunction with the use of fully-adhered membranes, a protective layer shall be provided over the waterproofing membrane immediately after testing is completed to prevent rupture or damage during subsequent Construction Activities.

(iv) For mined and cut-and-cover emergency ventilation Structures that incorporate a permanent cast in-situ concrete or shotcrete lining, the use of a spray-on waterproofing membrane may be considered subject to the applicable performance criteria being met. Where steel fibres are utilized, the waterproofing membrane shall be protected from punctures.

(v) For bored Tunnels that incorporate a permanent pre-cast concrete segmental lining or similar, Project Co must provide a water sealing system consisting of an elastomeric gasket designed for all anticipated combinations of offsets and gaps with a minimum sealing pressure of two times the maximum anticipated hydrostatic or grouting pressure, whichever is greater.

(h) Fire Resistance

(i) Structural integrity of Tunnels subjected to the Project defined Design fire outlined in Part 3 Article 8 – Tunnel and Station Ventilation Design Criteria, shall not be compromised during the fire event. Explosive spalling of concrete shall be mitigated by methods such as the inclusion of micro polypropylene fibres to the concrete mix for permanent linings or providing a fire resistant interior lining. The development of gas temperature shall correspond to the temperature versus time curves shown in the ITA Fire Guidelines Figure 2.4 unless Project-specific curves are developed by Project Co. The integrity of a Tunnel following exposure to a fire shall be checked, taking into account degradation in material properties due to temperature; Tunnels may require repair but shall not collapse. Guidelines in the ITA Fire Guidelines shall be used for evaluating fire resistance.

(ii) All structural steel members shall be protected from direct fire exposure based on the specified fire intensity and duration outlined herein. If steel members are protected with concrete encasement, the minimum concrete cover shall be 50mm.

(i) Loads and load combinations

(i) Loads and Load combinations are based on the nomenclature and combinations stipulated in Annex C of the CAN/CSA A23.3 Design of Concrete Structures.

(ii) Temporary excavation support and initial support including but not limited to rock dowels, lattice girders, canopy tubes, and spiles must not be used as measures to relieve loads on a permanent structural lining. Where permanent

shotcrete linings are installed load sharing will be allowed if it is substantiated through analysis by Project Co.

(iii) Permanent linings for Tunnels between a point 60m east of the eastern limits of Metcalfe Street and Campus Station shall be designed and constructed as Undrained. Other Tunnel reaches may be designed and constructed as drained or undrained at the discretion of Project Co subject to the determination that Drained Tunnels shall not cause detrimental impacts to groundwater levels as detailed in the hydrogeological impact assessment and associated risk assessment to be completed by Project Co.

(iv) Structural Dead Loads (D)

A. Dead loads of structural and non-structural elements shall be based on unit weights and computed volume of the materials.

(v) Live Loads (L)

A. Design live load shall consist of any non-permanent load placed on or in the Tunnel. Where vehicles can gain access above the Tunnel, the Tunnel shall be designed for traffic loading.

B. Train Loads

i. Structures shall be designed to support the loads from the LRV where applicable.

ii. Structures shall be designed to prevent collapse and minimize damage from derailment. Track guard rails for derailment prevention shall be provided at the locations where primary structural elements, such as columns, cannot be otherwise protected by benches, crash barriers or similar structures. Where emergency guard rails cannot be provided or are ineffective in preventing impact, columns situated within 7.5m as measured from the centerline of a Track and not protected by reinforced concrete benches, platforms or crash barriers, shall be designed to withstand derailment forces. For individual columns, this load shall be considered to be a point load in the most critical direction and for wall piers or crash barriers, the load may be distributed over an area not greater than 1.5m wide by 0.6m high. Derailment shall be considered an extreme case event, and the load factor associated with it may be taken as 1.0. The derailment load shall be taken in combination with the permanent dead and live loads, and 50% of non-permanent live loads of the structure. Alternatively, a redundant load path shall be provided. Where a group of columns is found to be vulnerable to derailment, the effect of any single column being removed shall be investigated with the intent of

checking that progressive collapse will not occur with the failure of one column. This condition shall also be analyzed with a load factor of 1.0.

iii. Vent shaft damper supports, ancillary walls and doors located within or adjacent to the running Tunnels and the divider walls within the running Tunnels shall be designed to withstand the air pressures generated by moving Trains. The maximum values of these reversible air pressures shall be calculated by a Tunnel ventilation Professional Engineer. These elements shall also be designed for cyclic loading and the cyclic loading shall correspond to a minimum of 4 million cycles, and its magnitude shall be obtained from the Tunnel ventilation Professional Engineer. For cross passages provided with one or a pair of doors on each trackside, the extreme loading condition of simultaneous pressure and suction on a single door from Trains moving on both Tracks shall also be considered. This loading condition relates to the unlikely event of a door left open on the opposite side, and need not be considered to be a cyclic application. Load factors shall be appropriately reduced for extreme loading conditions. Walls, doors and damper supports in fan and vent shafts not located adjacent to Stations or portals shall be designed to withstand the pressure transient of running Trains and for air pressures due to ventilation operations, as determined by Project Co.

(vi) Rock and Earth Loads (H)

A. Rock and earth loads on permanent linings shall be evaluated with state-of-the-practice numerical analysis methods used for determining the requirements for temporary excavation support and/or initial support. Rock loads may be checked using the methodology developed by Terzaghi and described in Proctor & White (Proctor, 1977). Rock wedge loads on the permanent lining due to deterioration of the temporary excavation support and/or initial support shall be determined using key block analyses and empirical methods using rock mass classification indices. Time dependent deformation (swelling) shall be evaluated numerically. A load factor of 1.5 shall be applied to these loads.

B. The Tunnel Design shall consider the effects of potential settlement of the Tunnel, Existing Adjacent Structures, and the surrounding ground during the Design Life.

(vii) Hydrostatic Loads (F)

A. No hydrostatic pressure shall be applied to Drained Tunnels. The Design shall consider the effects of blockage of the drainage system.

B. Undrained Tunnels shall be designed for the 100 year ground water table as established in the detailed hydrogeological impact assessment and associated risk assessment prepared by Project Co with a load factor of 1.25. Alternatively, the water table shall be assumed to be at ground level and a load factor of 1.1 shall be used.

(viii) Construction Loads (S)

A. Construction loading due to Equipment located on or adjacent to Tunnels shall be accounted for in the Design.

(ix) Wind Loads (W)

A. Wind loads shall be applied to facade walls where applicable.

(x) Seismic Demands (E)

A. Refer to Section 2.5 in this article for seismic loading.

(xi) Thermal and Shrinkage Loads (T)

A. Minimum reinforcing for temperature and shrinkage stresses shall be provided according to CAN/CSA A23.03. The spacing of this reinforcement shall be less than 3 times the member thickness or 500mm, whichever is less.

B. The minimum reinforcing ratio for the permanent linings of Tunnels shall be 0.25% of the gross concrete section.

(xii) Load Factors and Load Combinations

A. Load factors and load combinations for temporary and permanent Design of Tunnels are provided in the Table below. These load combinations are considered a minimum requirement and any additional critical load combinations shall be considered by Project Co.

		Permanent Loads				Transitory Loads		Exceptional Loads	
		1	2	3	4	5	6	7	8
		D	H	F	S	L	T	E	
Service Limit State, (SLS)									
I	Uplift Check (FS > 1.10)[Note 1]	0.9	0.9	1.0					
II	Construction[Note 2]	1.0	1.0	1.0	1.0				
III	In-Service[Note 3]	1.0	1.0	1.0	1.0				
Ultimate Limit State, (ULS)									
IV	Construction[Notes 2,4,5,6,7]	αD	αH	αF	1.5	1.5	1.25		
V	In-Service[Notes 3,4,5,6,7]	αD	αH	αF	1.5	1.5	1.25		
VI	Earthquake[Note 8]	αD	1.0	1.0	1.0	0.5		1.0	

		α Max LF	α Min LF	Definition
D	Dead	1.25	0.9	self-weight as applicable
H	Earth (At-rest or Active)	1.5	0.85	
F	Fluid (Hydrostatic)	1.25	0.85	NLW, NHW, 100 Yr Flood; use NLW & NHW for Construction related LC's
S	Surcharge (Existing or Future)	1.5	0.0	from existing or future structures within a given zone of influence
L	Live	1.5	0.0	inlcudes pedestrian, construction, traffic, train (VIA) & LRV
T	Temperature, Shrinkage & Creep Effects	1.25	0.0	
E	Earthquake	1.0	0.0	

Notes:

1 applies to construction and in-service; for construction, assume no earth cover for cut & cover, assume F at NHW for construction and at 100 Yr for in-service
2 assume no earth cover for cut & cover, consider F at NLW & NHW, only consider existing S if present.
3 consider F at 100 Yr, consider existing S if present, and future S.
4 consider with maximum vertical and maximum horizontal loading, consider with and without L, consider with and without T.
5 consider with maximum vertical and minimum horizontal loading.
6 consider unbalanced from left to right considering maximum vertical and horizontal loading on left and minimum vertical and horizontal on right.
7 consider unbalanced from right to left considering maximum vertical and horizontal loading on right and minimum vertical and horizontal on left.
8 assume 0.9 for earth cover, consider F at NLW & NHW, consider existing S if present, and with and without future S, consider with and without L.

2.5 Seismic Design and Analysis

(a) Performance requirements

(i) The seismic evaluation of Tunnels shall be based on a two-level Design approach which is summarized as follows. Consideration shall be given to both the ODE, which has a mean return period of 475 years, and the higher level MDE, which has a mean return period of 2,475 years. The performance requirements for these two levels of ground motion are as follows:

A. ODE: The Tunnels shall remain fully operational, shall be returned to operations after an inspection, and have experienced only minimal damage. Minimal damage is defined as not allowing yielding in reinforcement and ensuring that the structural response is essentially elastic during this level of event; and

B. MDE: Tunnels shall provide life Safety and not collapse under this event. The Design shall ensure no structural failure of any elements of the Tunnels. Inelastic response of the permanent linings could occur and yielding of reinforcement, cracking and spalling of concrete is expected under this event. The maximum strain under service load combinations, including seismic demands, shall be limited to:

i. Concrete compressive strain: 0.003; and

ii. Reinforcing steel tensile strain: 0.006.

(b) Seismic Analysis

(i) During seismic events, the Tunnels shall remain in intimate contact with the ground.

(ii) The procedure for seismic Design of Tunnels shall be based on the ground deformation approach. The Tunnel shall be designed to accommodate the deformations imposed by the ground before, during and after a seismic event, and the effects of soil structure interaction shall be taken into consideration.

(iii) For Tunnels, three methods may be used for seismic analysis: closed-form solutions, racking analysis, and dynamic analysis. The suitability of each of these methods depends on the geometry of the Tunnel and the complexity of the surrounding ground.

(iv) The appropriate level and scope of the seismic analyses for each type of Tunnel shall be determined by Project Co. The results of the closed-form solutions or racking analyses shall be used as a basis for determining the need and scope of the more detailed dynamic analyses, and whether two-dimensional or three-dimensional analyses may be required.

ARTICLE 3 CUT-AND-COVER STRUCTURES

3.1 Scope

(a) The scope of work includes Designing, furnishing, and constructing, cut-and-cover Structures, including:

(i) Tunnels not constructed by SEM or TBM methods;

(ii) Subsurface entry and exit shaft enclosures, emergency ventilation Structures, and cross passageways not constructed by SEM or TBM methods;

(iii) Temporary excavation support and underpinning systems; and

(iv) Temporary traffic support, including pedestrian, vehicular and rail traffic, as applicable.

3.2 Design and Construction Criteria

(a) Project Co shall design for temporary excavation support, underpinning, and temporary traffic support, including pedestrian, vehicular and rail traffic systems that, in conjunction with the selected means and methods for excavation and Construction of the cut-and-cover structures is in compliance with the requirements of this Project and Environmental Laws.

(b) Project Co shall design permanent cut-and-cover Structures that are durable and structurally sound. Project Co shall ensure that the components are compatible with its selected Construction Equipment, means, methods, procedures, and minimum Design and performance criteria.

(c) For the purpose of underground construction equipment design and operation, the cut-and-cover tunnels shall be classified as 'potentially gassy' in accordance with the US Department of Labor OSHA Part 1926.800.

(d) Project Co shall provide continued undisrupted service and access to all VIA Rail Platforms at Train Station as indicated in Part 1 Article 22 – Implementation Constraints.

(e) Blasting shall be performed in accordance with Schedule 17 – Environmental Obligations and City of Ottawa Standard Tender Documents for Unit Price Contracts Special Provision F-1201 Use of Explosives.

(f) Where exterior water proofing of Existing Adjacent Structures, adjacent to cut-and-cover excavations, is required to be removed to facilitate Construction or is otherwise damaged during Construction, it shall be repaired or replaced in-kind by Project Co to insure future leakage into Existing Adjacent Structures is less than or equal to pre-construction conditions.

(g) Qualifications:

(i) Design of excavation support systems and temporary traffic support, including pedestrian, vehicular and rail traffic support systems shall be performed by a Professional Engineer; and

(ii) Staff for Design and Construction of cut-and-cover structures shall include personnel who have verifiable Design and Construction experience in cut-and-cover structures Work.

3.3 Limitations on Means and Methods

(a) Cut-and-cover construction methods shall not be permitted from 30m west of to 30m east of the Rideau Canal walls inclusive.

(b) Cut-and-cover construction methods shall not be used from the escarpment face at the west portal to Bronson Avenue (i.e. through or adjacent to the NCC owned Bronson Park).

(c) Temporary excavation support wall systems used in the soil over burden in the East Portal area shall be rigid, impervious systems such as secant pile walls. Due consideration shall be given to limiting groundwater movement into the excavation from any location.

(d) Temporary excavation support wall systems used below elevation 60 in the soil overburden along Rideau Street, between Colonel By Drive and William Street, shall be rigid and impervious systems such as secant pile walls. Due consideration shall be given to limiting groundwater movement into the excavation from any location.

(e) Temporary ground anchoring systems in overburden soils shall not be used in the East Portal Area.

(f) At the MSF, CN/VIA Rail Tracks shall be restored on the permanent cut-and-cover structure by use of a ballasted system. A direct fixation Track system shall not be used.

ARTICLE 4 BORED TUNNELS

4.1 Scope

(a) The scope of work includes Designing, furnishing, and constructing, bored Tunnels using a TBM.

4.2 Design and Construction Criteria

(a) Project Co shall provide a TBM capable of excavating and supporting the ground while complying with the requirements of this Schedule 15-2. Project Co shall be responsible for the Design of the TBM system, including backup Equipment, guidance systems, gas detection and monitoring systems, auxiliary systems, support Equipment, and other items necessary for the safe and sustained operation of the TBM including TBM mobilization and launching, TBM retrieval and disassembly, Tunnel muck and water handling, muck volume and backfill grout metering, initial support and permanent lining installation (including tail void grouting), maintenance of the TBM, ventilation, and water treatment and disposal systems, all in accordance with the requirements of this Project and Environmental Law. The TBM system shall be new or refurbished, and designed specifically to meet Project Co requirements for this Project.

(b) Project Co shall Design permanent linings which shall provide a durable, water-tight, structurally sound permanent lining meeting the requirements of this Project. Permanent linings shall be bolted and gasketed segmental pre-cast concrete or two-pass lining system comprising initial support, waterproofing, and a cast-in-place concrete or shotcrete permanent lining. In case of local enlargements and junctions with cut-and-cover Tunnels and mined structures, waterproofing and a cast-in-place concrete or shotcrete permanent lining may be used.

(c) If a bolted and gasketed segmental permanent lining is selected, the following additional criteria shall be met, in addition to other requirements of this Schedule 15-2.

(i) Project Co shall determine the configuration of individual segments erected to form a continuous reach of segment rings in accordance with the following criteria:

A. Tapered rings shall be used as the sole means for negotiating curves and correcting alignment. Packing shall not be used to negotiate curves or correct alignment;

B. Radial joints in adjacent rings shall be staggered so that there are no cruciform joints; and

C. Fabrication and erection tolerances shall be selected to assure that groundwater inflow criteria are met.

(ii) Project Co shall determine requirements for casting, curing, tail void grouting, handling, installation and TBM-induced loads, and repair procedures. Quality

control procedures shall be developed to assure consistent casting dimensions and quality throughout fabrication.

(d) Construction of Tunnels through the bedrock valley just east of Colonel By Drive shall consider the mixed faced conditions at the valley walls and highly variable soil and groundwater conditions within the valley. The following are acceptable options for excavation through this valley:

(i) Pre-excavation stabilization of the soil and mixed face conditions to allow non-pressurized face support; and

(ii) TBM excavation with pressurized face support.

(e) For the purpose of underground construction equipment design and operation, the bored tunnels shall be classified as 'potentially gassy' in accordance with the US Department of Labour OSHA Part 1926.800.

(f) Special Procedures for TBM excavation operations:

(i) Project Co shall develop and implement daily review meeting procedures to evaluate TBM excavation and support efficacy. These procedures shall include a review of the following and any additional issues determined necessary by Project Co:

A. General performance of the TBM and the initial support systems;

B. Convergence and settlement monitoring results;

C. Muck volume and backfill grout metering; and

D. Any corrective actions that are required.

(ii) Details of the process shall be outlined fully in a Support Management Controls Plan and daily review meeting plan.

ARTICLE 5 MINED STRUCTURES

5.1 Scope

(a) The scope of work includes Designing, furnishing, and constructing, mined Structures, as follows:

(i) Running Tunnels not constructed by TBM or cut-and-cover methods;

(ii) Local enlargements and niches, cross passages and sumps;

(iii) mined Stations; and

(iv) Underground parts of entry and exit shaft enclosures, emergency ventilation structures, and connecting Tunnels not otherwise constructed by cut-and-cover methods.

5.2 Design and Construction Criteria

(a) Project Co shall design for the initial support and permanent lining for mined structures, in conjunction with the selected means and methods for excavation and in compliance with specified Design and Construction criteria. Project Co shall be responsible for elements of Design and Construction in accordance with the requirements of this Project and Environmental Law.

(b) Initial support and permanent lining shall be designed for the anticipated load conditions on the completed Tunnel. Project Co shall ensure that the selected Construction Equipment, means, methods, and procedures meet the Design and performance criteria.

(c) For the purpose of underground construction equipment design and operation, the mined tunnels shall be classified as ‘potentially gassy’ in accordance with the US Department of Labor OSHA Part 1926.800.

(d) Blasting shall be performed in accordance with Schedule 17 – Environmental Obligations and City of Ottawa Standard Tender Documents for Unit Price Contracts Special Provision F-1201 Use of Explosives.

(e) Construction of mined Structures through the bedrock valley east of Colonel By Drive shall consider the mixed faced conditions at the valley walls and highly variable soil and groundwater conditions within the valley.

(f) Special Procedures for Determining Initial Support Requirements

(i) Project Co shall develop and implement daily review meeting procedures to evaluate the excavation and support measure requirements and efficacy. These procedures shall be established to authorize the excavation and initial support of a specific reach of the Project, and to confirm the combined behavior of the ground

and the initial support system for prior excavated reaches conform to the Design intent.

(ii) The procedures shall include review of:

A. General performance;

B. Convergence monitoring results;

C. Ground and groundwater monitoring and blast monitoring results;

D. Lining quality – profile, thickness and shotcrete strength results; and

E. Geological mapping.

(iii) Details of the process shall be outlined fully in a Support Management Controls Plan and daily review meeting plan.

(iv) The daily review meeting shall consider the review procedures and any corrective actions will be discussed.

ARTICLE 6 MECHANICAL DESIGN CRITERIA

(a) This article contains mechanical criteria developed for the OLRT above ground, at grade, and running structures and Tunnels, and where applicable the stations. These criteria govern the functional requirements for water and sewage systems, drainage facilities (except at-grade sections), and fire protection systems.

(b) These criteria are intended to promote uniformity of Design and standardization of Equipment, and its location throughout the OLRT System and are not intended to conflict with the minimum requirements of the current codes and standards adopted by the OBC. If a conflict is found, the most stringent shall apply.

6.2 Codes, Standards and Manuals

(a) The Design and Construction of the Works shall comply with the criteria contained in this Article, and all standards, regulations, policies, Applicable Law, guidelines or practices applicable to the Project, including but not limited to each of the following Reference Documents. In the event of a conflict between criteria, commitments or requirements contained within one document when compared with another, the more stringent shall apply:

(i) OBC;

(ii) OFC;

(iii) OESC;

(iv) CSA;

(v) CEC;

(vi) OHSA;

(vii) ARI;

(viii) AMCA Standard 210, Laboratory Methods of Testing Fans for Rating Purposes;

(ix) AMCA Standard 300, Test Code for Sound Rating Air Moving Devices;

(x) AMCA Standard 301, Methods for Calculating Fan Sound Ratings from Laboratory Test Data;

(xi) ANSI;

(xii) ASHRAE Handbooks;

(xiii) Standard 90.1-2010 – Energy Standard for Buildings Except Low-Rise Residential Buildings ASHRAE – permitted for Construction after December 31, 2011;

(xiv) Standard 62.1- 2010 – Ventilation for Acceptable Indoor Air Quality - ASHRAE;

(xv) MNECB;

(xvi) Green Energy Act, 2009;

(xvii) ASPE;

(xviii) ASME;

(xix) ASTM;

(xx) APTA, Rail Transit Committee, "Guidelines for Design of Rapid Transit Facilities";

(xxi) DOT, "Recommended Emergency Preparedness Guidelines for Rail Transit Systems";

(xxii) NEMA;

(xxiii) SMACNA;

(xxiv) TIAC;

(xxv) PDI;

(xxvi) UL;

(xxvii) ULC; and

(xxviii) NFPA – Particular references shall be made to the following sections of NFPA:

A. NFPA Standard 10, Portable Fire Extinguishers;

B. NFPA Standard 13, Installation of Sprinkler Systems;

C. NFPA Standard 14, Standpipe, Private Hydrant, and Hose Systems;

D. NFPA Standard 20, Installation of Stationary Pumps;

E. NFPA Standard 70, National Electrical Code;

F. NFPA Standard 90A,lnstallation of Air-conditioning and Ventilating Systems;

G. NFPA Standard 101, Life Safety Code;

H. NFPA Standard 130, Fixed Guideway Transit and Passenger Rail Systems;

I. NFPA Standard 204, Smoke and Heat Venting;

J. NFPA Standard 502, Standard for Road Tunnels, Bridges and Other Limited Access Highways;

K. NFPA Standard 1963, Fire Hose Connections; and

L. NFPA Standard 2001, Clean Agent Fire Extinguishing Systems.

6.3 General Requirements

(a) The requirements include mechanical systems located in the running Structures and Tunnels, and where applicable the Stations. Mechanical Design, Equipment, and installation shall comply with local Relevant Authority including but not limited to the following:

(i) No sanitary waste shall be permitted to enter the storm drainage system;

(ii) All valves and accessories shall be arranged in systemic manner in places accessible for operation;

(iii) Sleeves complete with waterproof seals shall be provided wherever pipes pass through structures, foundation walls, walls that are buried, or wherever a penetration requires a watertight seal;

(iv) All piping accessories shall be sized for trouble free balancing and operation;

(v) Drainage pipes shall not be routed through areas containing electrical, communication, or signalling Equipment;

(vi) Where flow of sanitary drainage systems to municipal sanitary sewer systems cannot be achieved by gravity, systems shall be complete with pumping stations;

(vii) All priming lines shall be insulated and heat traced;

(viii) Pumps located in sumps or pits shall be provided with extended grease lines terminating above the floor level at the top of the sump or pit;

(ix) Pumps located in sumps, pits or tanks shall be provided with a disconnect location outside the sump, pit or tank, with a second waterproof manual quick disconnect in the power line to the pump, to facilitate removal of the pump;

(x) Place floor-mounted Equipment on heavy-weight reinforced concrete housekeeping pads with chamfered edges;

(xi) All mechanical Equipment, piping, control valves, shut off valves, instruments, shall be permanently identified;

(xii) Provide electric disconnect switches for each mechanical Equipment; and

(xiii) All Equipment, pipes, supports, accessories, and their connections to the Structure, must be designed to resist seismic force and to accommodate building seismic deflection in accordance with OBC 4.1.8.17.

6.4 Sanitary Drainage

(a) The water collection system shall accommodate sanitary wastewater from the following sources:

(i) Elevator pits and elevator machine rooms;

(ii) Station public Areas (Platforms, Mezzanine and Street Level Floor Space);

(iii) Staircases;

(iv) Escalator Lower Pits;

(v) Station Room Areas;

(vi) Station sprinkler and standpipe Fire Protection Systems including associated Valve Rooms; and

(vii) Additional areas as required.

(b) Drainage Pump Stations

(i) Pump stations shall be provided for drainage from elevator pits, elevator machine rooms, and escalator lower pits.

(ii) The pump station shall consist of one pump, and concrete sump pit or steel tank ejector, with a gas tight cover.

(iii) Pumps shall be sized for hydraulic requirements based upon the Hazen and Williams formula using a “C” wet factor of 100.

(iv) Pump shall be automatic by the float controls and through a local on-off automatic switch.

(c) Sewage Pump Stations

(i) Sewage pump stations shall consist of two pumps located in a concrete sump, or a steel tank with a gas tight cover, served by 2-pumps floor mounted outside, adjacent to the tanks.

(ii) Pump shall be automatic by the float controls and through a local on-off automatic switch.

(d) Vent Systems

(i) Sections of horizontal vent pipework shall be constructed with a minimum 2% slope toward the soil and waste pipe being served.

6.5 Standpipe System

(a) Two separate water supply lines to each Station shall be utilized. One line shall serve domestic use, and the other line fire protection use.

(b) A manual, dry, Class I, standpipe system conforming to NFPA 14 shall be provided throughout each Tunnel section.

(c) The dry standpipe system including fire valves shall be located on the service way side of the Tunnel Track way.

(d) Components of the standpipe system shall include the following:

(i) Fire department connections at stations and emergency exit/service buildings;

(ii) Air release valve assemblies to accelerate the charging of the standpipe lines; and

(iii) Fire valves located at 76.2m intervals along the Tunnel.

(e) Fire department connections for standpipe systems shall be located so that the distance from a fire department connection to a hydrant is not more than 45m and is unobstructed.

(f) Fire valve sites shall incorporate a 65mm fire hose valve positioned to discharge perpendicular to the Track Alignment.

(g) Standpipe system shall incorporate manual drain valves.

ARTICLE 7 ELECTRICAL DESIGN CRITERIA

7.1 Introduction

(a) Electrical spaces shall be properly located and sized to facilitate the installation and maintenance of Equipment.

(b) Accessibility shall be provided to permit removal and replacement of major Equipment. These requirements are intended to promote uniformity in the Design approach and to standardize the type of Equipment and its location throughout the System.

(c) Electrical power distribution Equipment shall be heavy duty Construction, selected to provide Equipment longevity and be designed to provide lower arc flash potential during Maintenance, high arc flash energy dispersion.

(d) All electrical Equipment shall be individually identified by unique number matching Equipment schedule Designation. The label shape, letter size, color coding and background color shall be standardized for the Project. Project identifying labels shall be designated for: cable trays, conduits, junction boxes, cables/wires and all electrical and electronic Equipment. In addition to identification labels, approval labels shall be provided as required per CSA, ULC, or HOL.

7.2 Codes, Standards and Manuals

(a) The Design and Construction of the Works shall comply with the criteria contained in this Article, and all standards, regulations, policies, Applicable Law, guidelines or practices applicable to the Project, including but not limited to each of the following Reference Documents. In the event of a conflict between criteria, commitments or requirements contained within one document when compared with another, the more stringent shall apply:

(i) Refer to Part 5 Article 5 – Electrical Design Criteria for Design codes, standards and guidelines.

7.3 Basis for Design

(a) Electrical Load Classification

(i) Refer to the Station electrical Design Criteria outlined in Part 5, Article 5 – Electrical Design Criteria for electrical load classifications.

(b) Calculations

(i) Refer to Part 5 Article 5 – Electrical Design Criteria for calculations as follows:

A. Short-circuit;

B. Voltage drop; and

C. Lighting illumination level.

(ii) Arc flash hazard calculations shall be extended to the high energy low voltage Equipment with expected high arc fault current and/or protected by instantaneous only or time delayed protection settings.

(c) Protection for future growth for all major electrical Equipment feeders shall be provided. Before determining the size of service an economic analysis shall be made to determine the most feasible way of protecting for the future growth. Special consideration shall be given to requirements for load growth, for anticipated usage and life expectancy.

(d) Electrical Safety Provisions

(i) Equipment ground fault "annunciation only" shall be provided where EGFP is required by code or standard engineering practice for Equipment or feeders serving Level 2 Emergency Systems.

(ii) Personal ground fault protection shall be provided on branch circuits that have equipment or outlets for which personal protection is required by either code or standard engineering practice.

7.4 Functional Requirements

(a) Electrical Service

(i) For Tunnel services, Project Co shall distribute the required power from the HOL switchgear to provide safe and reliable power to satisfy operational and Emergency requirements. All related Tunnel electrical distribution shall comply with applicable codes and standards, in particular related to Emergency and safety critical systems including and not limited to.

(ii) Primary switching rooms for incoming service, including any underground TPSS, shall be:

A. designed in partnership with HOL and in accordance to HOL Specification GCS0002: Primary Voltage Service Specification;

B. at grade or within five (5) meters below grade with two walls on the outside to allow ease of access for HOL incoming feeders and designed for a three (3) hour fire envelope;

C. a minimum of 5.5m wide, 9.5m long and a ceiling height of 3.2m; and

D. coordinated with HOL in terms of switchgear location and placement within the rooms.

(b) Metering and Monitoring

(i) Remote monitoring system shall be provided for:

A. Tunnels main panelboards breakers position; and

B. Voltage availability at the main buses.

(c) Duct banks and Handholes

(i) Duct banks and Handholes shall be designed in accordance with the seismic criteria defined for the Project. Duct banks shall be designed to include at least 25% spare capacity to protect for future growth and expansion. In addition there shall be space allowance for a 24 way fibre to be installed for a separate highways IT network, the duct size for this fibre shall be a minimum of 102mm (4 inch) diameter. Smaller sizes shall be approved by the City Highway Operations department. All ducts to be roped.

(d) Grounding and Bonding

(i) All non-current-carrying metal enclosures and all alternating current Equipment enclosures shall be securely connected/bonded to the grounding system.

(e) Emergency and Standby Power Sources

(i) Refer to Part 5 Article 5 – Electrical Design Criteria for emergency power services.

(f) General Purpose Receptacles

(i) General purpose receptacles shall be GFI. No more than two outlets shall be connected to a branch circuit.

(g) Lighting

(i) Lighting Design shall be consistent across all Tunnels. Standardization of lighting system components shall be provided.

(ii) Lighting levels shall define and differentiate between task areas, decision and transition points, and areas of potential hazard. Lighting shall be designed to minimize glare and provide uniform distribution. Luminaires shall be selected, located, and/or aimed to accomplish their primary purpose while producing a minimum glare and interference with task accuracy for Train Driver.

(iii) Emergency power shall be available at stable system voltage within 10 seconds or less. All batteries shall be sized to continuously carry the rated illumination for the greater of the following; the minimum time required for evacuation or as required by applicable code.

(iv) Lighting system shall be designed so that the failure of any single luminaire or lighting circuit does not leave an area in total darkness.

(v) Project Co shall Design and Construct transitional lighting from underground to surface sections of the Project. The length of threshold/transition lighting shall be based on operating speeds and the corresponding safe stopping distance. Project Co shall review and take into account the given criteria in the last edition of the American National Standard Practice for Tunnel Lighting – ANSI/IESNA RP-22 and TC – RTD 10 Transport Canada Road/Railway Grade Crossing Technical Manual: Guide for the Design of Roadway Lighting Transportation Association of Canada.

A. Lighting control systems shall be monitored and controlled through a facility BAS system. Where Facility remote control system is not provided central-key/timer control system including override switches for controls in service areas.

(vi) Lighting for exterior access to Tunnel areas shall be designed to consider security, CPTED and CCTV requirements.

(vii) Minimum illumination levels are outlined in Tables 3-7.1.

Table-3-7.1: Tunnels

Location	Average Minimum Lux	Emergency
Tracks, Cross-Overs and Catwalks	20	10
Track Switches	40	10
Tunnel	20	10
Tunnel Transition Zones	*Refer to 7.4 (g) (v)	

ARTICLE 8 TUNNEL AND STATION VENTILATION DESIGN CRITERIA

8.1 Scope

(a) The scope includes the requirements for the operation and control of the emergency ventilation systems for the Tunnels and for the Stations.

8.2 Codes, Standards and Manuals

(a) The Design and Construction of the Works shall comply with the criteria contained in this Article, and all standards, regulations, policies, Applicable Law, guidelines or practices applicable to the Project, including but not limited to each of the following Reference Documents, In the event of a conflict between criteria, commitments or requirements contained within one document when compared with another, the more stringent shall apply:

(i) OBC;

(ii) OFC;

(iii) OESC;

(iv) CSA;

(v) CEC;

(vi) OHSA;

(vii) AMCA Standard 210, Laboratory Methods of Testing Fans for Rating Purposes;

(viii) AMCA Standard 300, Test Code for Sound Rating Air Moving Devices;

(ix) AMCA Standard 301, Methods for Calculating Fan Sound Ratings from Laboratory Test Data;

(x) ANSI;

(xi) ASHRAE Handbooks ;

(xii) MNECB;

(xiii) ASME;

(xiv) ASTM;

(xv) APTA, Rail Transit Committee, Guidelines for Design of Rapid Transit Facilities;

(xvi) DOT Recommended Emergency Preparedness Guidelines for Rail Transit Systems;

(xvii) NEMA;

(xviii) SMACNA;

(xix) ULC; and

(xx) NFPA - Particular references shall be made to the following sections of NFPA:

A. NFPA Standard 70, National Electrical Code;

B. NFPA Standard 90A,lnstallation of Air-conditioning and Ventilating Systems;

C. NFPA Standard 101, Life Safety Code;

D. NFPA Standard 130, Fixed Guideway Transit and Passenger Rail Systems;

E. NFPA Standard 204, Smoke and Heat Venting; and

F. NFPA Standard 502, Standard for Road Tunnels, Bridges and Other Limited Access Highways.

8.3 Emergency Ventilation

(a) System Operation

(i) Normal Operation

A. Ventilation during normal operation is provided by the "piston effect" of the Trains moving through the Tunnels. In order to facilitate this effect, emergency ventilation shafts are located near the ends of the Station Platforms and fan bypass dampers are in the normally open position.

B. If not operating in a fire Emergency scenario, the emergency ventilation fans shall be used to maintain air temperature Design Criteria.

(ii) Emergency Operation

A. The modes of operation shall be initiated from the TSCC through the SCADA system.

B. The SCADA system shall include a schematic display of the Tunnel system indicating all of the ventilation elements to be activated and their mode of operation. Upon examination of the display by the Driver to

assure the proper response by the emergency ventilation system, the Driver will energize the designated sequence which in turn will control each of the displayed ventilation elements to function in the manner indicated. The SCADA system shall provide a means of detection of noxious or flammable gases.

C. Local controls shall be permitted to override the TSCC in all modes in the event the operations control center becomes inoperative or where the operation of the emergency ventilation system components is specifically redirected to another site.

(b) Emergency Ventilation Fans for Stations and Tunnels

(i) Axial-Flow Fans - Station Emergency Ventilation Fans

A. Fans shall be of the axial-flow type, with internally mounted, directly driven motor. Fans shall be reversible, to one or both Tunnels.

B. Fans shall have adjustable-pitch blades, or variable frequency drive united fitted to permit changes in fan-operating characteristics to protect for either system or future system modification.

C. The minimum acceptable reverse (supply) flow capacity shall be 90 percent of the forward (exhaust) flow capacity.

D. Fans shall be selected to have a total efficiency of not less than 60 percent in the forward (exhaust) flow mode.

E. Each fan shall be provided with modular sound attenuators on both the inlet and discharge sides of the fan. Additional sound lining shall be provided as required so that maximum noise levels from ventilation systems do not exceed allowable limits.

F. Emergency ventilation fans and motors shall be capable of operating in an ambient temperature of 250ºC for a minimum of one hour

(ii) Jet Fans – Tunnel Emergency Ventilation Fans

A. Jet fans shall be of the vane-axial type, and shall have at least 95% capacity in reverse mode.

B. Jet fans shall be provided with appropriate sound attenuators. Jet fans and motors shall be capable of operating in an ambient temperature of 250ºC for a minimum of one hour.

C. Fan power curve shall not exceed 100 percent of the motor rating at any point. The brake horsepower for reverse (supply) flow shall not exceed the brake horsepower for (exhaust) flow.

(iii) Emergency Ventilation Dampers

A. Emergency ventilation dampers shall be heavy duty, industrial type with parallel blade Design. The dampers shall be capable of operating in ambient temperature of 250^{o}C for a minimum of one-hour and a static pressure reversal from plus 0.747 kPa to minus 0.747 kPa occurring during a maximum 30-second time interval. Any damper component shall be capable of operating in an ambient temperature of 250^{o}C for a minimum of one hour and a static pressure reversal from plus 0.996 kPa to minus 0.996 kPa occurring during a maximum of a 30 second time interval. End/limit switches shall be provided for each fan damper section to allow remote monitoring of the "closed" and "open" damper positions.

8.4 Smoke Dispersion/Recirculation Study

(a) Project Co shall undertake a smoke dispersion analysis for emergency ventilation systems to demonstrate the following:

(i) Smoke discharged from emergency ventilation shafts is not drawn into the Station entrances or other Station air intakes; and

(ii) Smoke discharged from emergency ventilation shafts is not drawn into entrances or air intake shafts of adjacent buildings.

(iii) Smoke re-circulation studies shall meet the requirements of NFPA 130;

(b) Based on the study, the location of the Station facilities shall be adjusted to minimize recirculation impacts or other mitigating measures shall be identified and implemented.

8.5 Fire Life Safety Protocols

(a) Project Co shall be responsible for developing, in consultation with the City, fire life Safety protocols for the safe operation of the LRT System as follows:

(i) The development of the protocols shall involve a collaborative process involving Project Co, the City and the Relevant Authority over fire life Safety issues. This process shall be led and managed by Project Co;

(ii) The protocols shall include fan ventilation protocols for the Emergency evacuation and ventilation of Stations and Tunnels in response to all potential fire life Safety risks including but not limited to risks identified as a result of risk analysis;

(iii) Fan ventilation protocols to outline the responsibilities of Project Co, the City (including the TSCC) and first responders;

(iv) The role of fire control panels in Stations is to be defined as part of the overall fire life Safety system;

(v) Standard operating procedures (SOP) are to be developed and agreed upon by all parties; and

(vi) The development of SOPs and fire life Safety protocols shall be in full compliance with Part 1 Article 9 – Safety and Security Certification and this article.

8.6 Design Criteria

(a) The Design Criteria outlined in Tables 3-8.1, 3-8.2, 3-8.3 and 3-8.4 shall apply to the Tunnel and Station emergency ventilation systems including the associated Tunnel ventilation shaft structures and Equipment.

Table 3-8.1: Outside Ambient Design Conditions (Ottawa, ON)

Description	Data	Source	Comment
Summer dry bulb Design temperature	28.7°C	ASHRAE Fundamentals	1% occurrence
Summer wet bulb Design temperature	20.5°C	ASHRAE Fundamentals	1% occurrence
Winter dry bulb Design temperature	-23.5°C	ASHRAE Fundamentals	99.6% Design value

Table 3-8.2: Air Temperature Design Criteria

Tunnel – Normal Operation	
Preferred Maximum Temperature	35°C
Maximum Average Temperature	40°C
Maximum Peak Temperature	45°C
Tunnel – Congested Operation	
Maximum Temperature for Train A/C and electrical Equipment	38.9°C
Maximum Local Peak Temperature	45°C
Tunnel – Emergency Operation	
Maximum 6 min average Temperature in Evacuation Pathways	48.9°C

Table 3-8.3: Air Velocity Criteria

Location	Description	Velocity
Public Areas of Station	Maximum velocity	5.08 m/s

Location	Description	Velocity
Exterior inlets and outlets	Emergency Operation	10.16 m/s based on net free area of terminal gratings
Emergency ventilation shafts and ducts	Emergency Operation	9.14 m/s max
Tunnels	Emergency Operation – Smoke Control	Critical velocity – varies for each Tunnel section
	Emergency Operation - Maximum	11.18 m/s in areas where Passengers may be present

Table 3-8.4: Design Fire Data

Location	Max. Fire Size
Tunnels/Stations (LRT)	13.1 MW

(b) Noise Criteria

(i) Noise criteria shall comply with the Guidelines for Design of Rapid Transit Facilities as listed by the Rail Transit Committee, APTA as outlined in Table 3-8.5.

Table 3-8.5: Ventilation Equipment Noise Limits

Area	Target Noise Level (NC)
Platforms	45
Mezzanines	45
Station Booths	40
Retail	45
Emergency Operation	70

(ii) During Emergency operations, the Tunnel ventilation noise shall not exceed Lmax 85 dB(A) within the Tunnel, and combined with the ventilation noise must not exceed NC 70 as measured within the Station.

(iii) Refer to Schedule 17 – Environmental Obligations for information on external noise level restrictions.

(c) Pressure Wave Criteria at Stations

(i) Criteria for pressure wave at Stations resulting from Train movements are outlined in Table 3-8.6.

Table 3-8.6: Normal and Congested Operation

Normal and Congested Operation	
Maximum Isolated Pressure Pulse Not to Exceed Within a Period of 4 seconds	2.99 kPa
Maximum Repeated Pressure Pulses Not to Exceed Within a Period of 1.7 seconds	0.697 kPa

(d) Smoke ventilation shaft locations

(i) Four (4) ventilation shafts shall be provided at each Underground Station. To alleviate the air pressure effects of the column of air in front of an approaching train on passengers on Station Platform areas (draught relief), the shafts shall be located at the extremities of the Station Platforms i.e. one at each end of the Platforms for side Platform Station arrangement, or at each corner of the Station box for a centre Platform Station arrangement;

(ii) Openings for emergency smoke ventilation shafts on the surface shall be separated by a minimum horizontal distance of 32 m from the closest Station entrance or exit and air intakes operating in supply mode serving the Station. Modification to this minimum separation distance may be accepted where it is supported by a detailed smoke dispersion/recirculation study in accordance with Section 8.4 of this schedule;

(iii) Openings for emergency smoke ventilation shafts on the surface shall be separated by a minimum horizontal distance of 12 m from unprotected outside air intake or other openings of all other adjacent structures;

(iv) Where the above distance is not practical, the minimum distance shall be 4.5 m if the closest shaft exit is raised a minimum of 2.5 m above the Station entrance or exit, unprotected outside air intake or other openings;

(v) The minimum distance at grade between the edges of adjacent openings for outside air intakes, protected by smoke dampers, and ventilation shafts shall be as follows:

$$d = 0.25 \times (L1 + L2)$$

Where: d = minimum distance between the edges of the adjacent openings, in meters,
L1 + L2 = lengths of the adjacent parallel sides of the openings, in meters

(vi) Ventilation shaft openings on the surface shall be located to provide as direct a route to atmosphere as possible, so as to facilitate ease of airflow to and from the underground sections;

(vii) Ventilation shafts shall not terminate in driveway surfaces at parking garage entrances or other surfaces utilized for daily vehicular access;

(viii) Where not located in a sidewalk, vent shafts shall terminate a minimum 150 mm higher than any adjacent surface to exclude run-off drainage into the shaft; and

(ix) Gratings and louvers shall be of high security and tamper proof construction.